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Faulting and hydration of the Juan de Fuca plate system

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ABSTRACT

Multichannel seismic observations provide the first direct images of crustal scale normal faults within the Juan de Fuca plate system and indicate that brittle deformation extends up to ~200 km seaward of the Cascadia trench. Within the sedimentary layering steeply dipping faults are identified by stratigraphic offsets, with maximum throws of 110±10 m found near the trench. Fault throws diminish both upsection and seaward from the trench. Long-term throw rates are estimated to be 13±2 mm/kyr. Faulted offsets within the sedimentary layering are typically linked to larger offset scarps in the basement topography, suggesting reactivation of the normal fault systems formed at the spreading center. Imaged reflections within the gabbroic igneous crust indicate swallowing fault dips at depth. These reflections require local alteration to produce an impedance contrast, indicating that the imaged fault structures provide pathways for fluid transport and hydration. As the depth extent of imaged faulting within this young and sediment insulated oceanic plate is primarily limited to approximately Moho depths, fault-controlled hydration appears to be largely restricted to crustal levels. If dehydration embrittlement is an important mechanism for triggering intermediate-depth earthquakes within the subducting slab, then the limited occurrence rate and magnitude of intraslab seismicity at the Cascadia margin may in part be explained by the limited amount of water imbedded into the uppermost oceanic mantle prior to subduction. The distribution of submarine earthquakes within the Juan de Fuca plate system indicates that propagator wake areas are likely to be more faulted and therefore more hydrated than other parts of this plate system. However, being largely restricted to crustal levels, this localized increase in hydration generally does not appear to have a measurable effect on the intraslab seismicity along most of the subducted propagator wakes at the Cascadia margin.

1. Introduction

Oceanic plates carry physically and chemically bound water into subduction zones (e.g., Peacock, 1990; Meade and Jeanloz, 1991; Moore and Vrolijk, 1992; Ranero et al., 2003). As the subducting oceanic plates descend, and the pressure and temperature rise with the increasing depth, the water stored in the plates is gradually released through a series of dehydration reactions (e.g., Meade and Jeanloz, 1991; Kirby et al., 1996; Peacock, 2001; Hacker et al., 2003a,b). This free water is believed to strongly affect a number of processes important to natural hazard studies. The released water promotes partial melting responsible for arc magmatism (Tatsumi and Eggins, 1995; Kirby et al., 1996), can affect the mechanical characteristics of an interplate interface (Shipley et al., 1994; Nedimović et al., 2003a; Kodaira et al., 2004), and induces intraslab earthquakes at intermediate depths (~50–300 km) (Raleigh and Paterson, 1965; Meade and Jeanloz, 1991; Kirby et al., 1996).

Significant effort has therefore been directed toward understanding dehydration processes during subduction, with particular emphasis on the influence these processes may have on the depth-distribution of intraslab seismicity (Meade and Jeanloz, 1991; Peacock, 2001; Hacker et al., 2003a,b; Jung et al., 2004). To fully evaluate the importance of slab dehydration, however, it also is necessary to constrain the amount of water bound in the slab when it is subducted at the trench (Ranero et al., 2003). We focus our effort on determining the penetration depth and relative volume extent of oceanic slab hydration offshore Cascadia margin. For this purpose, we process ~1500 km of ridge-flank multi-channel seismic (MCS) data collected in 2002 during the EW0207 cruise and compile a database of seismic reflection profiles from all earlier crustal scale MCS surveys (streamers 2.4 km or longer) across the Juan de Fuca plate system. The spatial distribution of the MCS lines examined is shown in Fig. 1, along with magnetic isochrones (Wilson, 2002) and the locations

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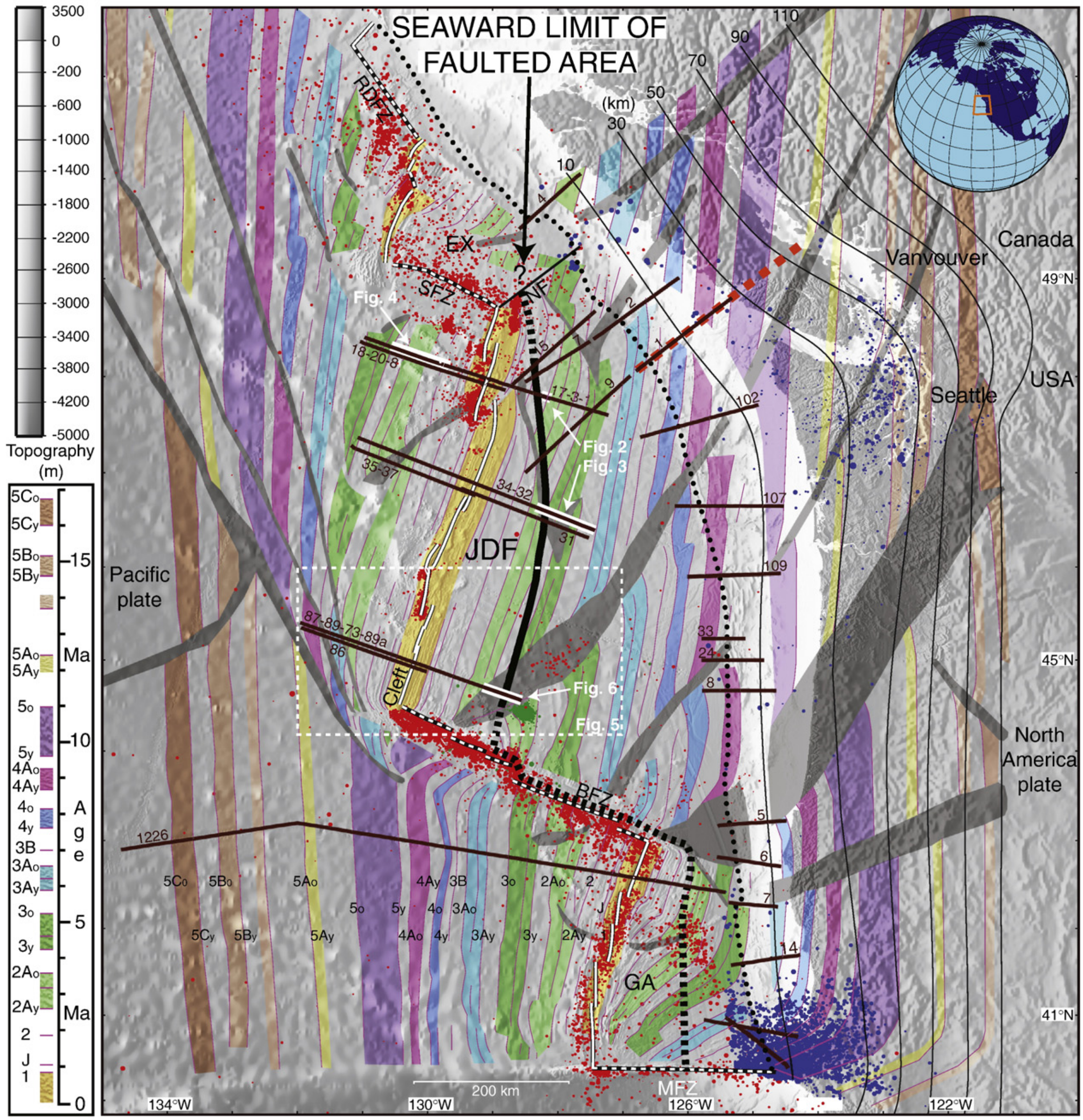

Fig. 1. Juan de Fuca plate regional seismicity and crustal age superimposed over grayscale bathymetry. Crustal scale marine MCS profiles from eight regional surveys are shown using thick brown lines. Line numbers are defined as in original surveys. White sections on transects 17-3-1, 34-32 and 87-89-73-89a represent the locations of the images shown in Figs. 2, 3, 4 and 6 respectively. Dashed white rectangle outlines the area shown in Fig. 5. Thick dashed orange line shows the location of the thermal profile of Wang et al. (1995) crossing the northern Cascadia margin. Thick black line on the subducting plates outlines the seaward limit of the region of extension or transtension where normal faulting is observed (solid) or inferred (dashed). Dotted black line shows the location of the trench. Long N-trending black isodepth lines (McCrory et al., 2004) show the position of the Juan de Fuca oceanic slab beneath North America. Red dots are earthquakes recorded from 1991 to 2004 by the Sound Surveillance System (SOSUS) (Fox et al., 1994; http://www.pmel.noaa.gov/vents/acoustics/autochart/GetPosit.html). Blue dots are intraslab earthquakes with magnitudes >2 recorded from 1975 to 2002 and extracted from the Advanced National Seismic System catalog (McCrory et al., 2004). Green dots near the eastern end of transect 87-89-73-89a represent the SOSUS-detected earthquake swarm from April 2008. White lines with black edges are the interpreted traces of the ridge axis; dashed over fracture zones. Thin pink lines are magnetic isochrons that outline color shaded magnetic anomalies 1 through 5C, and grey shading outlines propagator wakes (Wilson, 1988; 2002). JDF–Juan de Fuca plate; EX–Explorer plate; GA–Gorda deformation zone; RDFZ–Revere–Dellwood fracture zone; SFZ–Sovanco fracture zone; NF–Nootka fault; BFZ–Blanco fracture zone; MFZ–Mendocino fracture zone. Inset in the upper right corner shows the location of the study area with respect to North America.

of Cascadia margin earthquakes believed to be spatially restricted to the Juan de Fuca plate and subducting slab (Fox et al., 1994; McCrory et al., 2004).

2. Study area

The study area shown in Fig. 1, located offshore western North America, encompasses the Juan de Fuca ridge and plate system (Explorer, Juan de Fuca and Gorda ridges and plates), Cascadia deformation front, Nootka fault, and Sovanco and Blanco fracture zones. The Juan de Fuca ridge system, a NNE-oriented intermediate-rate spreading center, is located at the boundary between the Pacific plate and the Juan de Fuca plate system. The full spreading rate along the Juan de Fuca ridge is 56 mm/yr, and 56 mm/yr and less along the Explorer and Gorda ridges (e.g., Wilson, 1993). The Cascadia deformation front marks the surface trace of the interface between the Juan de Fuca and North America plates. The Nootka fault is the boundary between the Explorer and the Juan de Fuca plates, and